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PHOTO STRATIFICATION IMPROVES NORTHWEST TIMBER VOLUME ESTIMATES

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ABSTRACT

Data from extensive timber inventories of 12 counties in western and central Washington were analyzed to test the relative efficiency of double sampling for stratification as a means of estimating total volume. Photo and field plots, when combined in a stratified sampling design, proved about twice as efficient as simple field sampling. Although some gains were made by stratifying into only two classes--forest and nonforest--substantially greater gains accrued when the forest plots were further stratified into timber volume classes. Optimum allocation of field plots was only slightly more efficient than proportional allocation.

Keywords: Double sampling, photo sampling, timber volume estimates.

INTRODUCTION

An estimate of total timber volume is a major objective of almost every forest inventory. Some inventory organizations use simple random or systematic field sampling to obtain this estimate. Others prefer a stratified sampling design that utilizes aerial photographs to divide the inventory unit into several volume classes or strata from which field plots are drawn. If the stratification is successful, i. e., if the field plots have really been sorted into meaningfully different groups, then a more precise estimate of total volume should be obtained for the same cost.

Although stratification may be by either type map or photo sampling, type mapping is not usually undertaken unless the type map itself is an inventory objective, since photo plots, when combined with field plots in a stratified sampling design, do a better job of stratification at less cost.

Although double sampling for stratification offers the potential for estimating timber volumes more efficiently than a simple field plot sample, there is no guarantee of success. The inventory forester who wonders how well the method might work for him must be guided primarily by the experience of others who have used it. In particular, he will need to know whether double sampling will result in lower sampling errors than might be obtained by simple field surveys of equal cost, and if so, how much of a reduction in sampling error he can expect. If he decides to adopt the method, he will need to decide how many strata to identify and what boundaries to give them. In addition, he will need to decide how to allocate the field samples among these strata. The theoretical basis for answering these questions can be found in Cochran (*5*). Unfortunately, localized reports on the results of practical experience are harder to find. Although a number of inventory organizations in the United States and at least one in Canada use double sampling for stratification, only a few have published results and these are inconsistent (*1*, *2*, *4*, *7*).

Additional reports on field experience with forest inventory applications of double sampling for stratification are needed, particularly for the Pacific Northwest where no such published data are available. To help fill this need, I have undertaken to compare simple field sampling with three types of double sampling as a means of estimating total volume. The basis for this comparison is data from recent double sampling inventories conducted by the Pacific Coast Forest Survey Unit of the U.S. Forest Service as a part of its regular inventory

program. The comparison is, however, limited to a consideration of the strata recognized in the inventories from which the data came. Questions about the optimum number and size of strata are unexplored as are questions about the efficiency of the designs tested in estimating volume for populations differing substantially from those sampled. I have, then, considered the following questions:

1. Is double sampling for stratification a more efficient means of estimating total volume than simple field sampling when applied to extensive forest inventories in the Pacific Northwest? If so, how much more?
2. Is stratification more effective when forest land is broken down into several volume classes than when stratification is confined to two classes--forest and nonforest? If so, how much more?
3. How much more efficiently can total volume be estimated if optimum allocation instead of proportional allocation[1/] is used to distribute the field plots among the various photo strata?

THE DESIGN: DOUBLE SAMPLING FOR STRATIFICATION

The design has been well described by many, including Cochran (*5*) and Bickford (*2*, *4*). Briefly, the sampling design, as applied to a forest inventory situation, consists of a relatively large number of photo plots distributed systematically over the inventory area. A photo interpreter classifies these photo plots and sorts them into volume strata. Then a subsample is drawn from each stratum for field examination. The gross area of the inventory unit is assumed to be known without error. To estimate the area in a stratum, the proportion of photo plots falling in that stratum--the stratum weight--is multiplied by the gross area in the unit. The stratum area is then multiplied by the mean field volume of the field plot subsample to provide an estimate of total volume in that stratum. The total volume estimate for the inventory unit is the sum of the stratum estimates.

Double sampling for stratification is by no means a new idea in forest inventory. The U.S. Forest Service's Northeastern Forest Survey Unit, for example, has used the design for 25 years and the Pacific Coast Survey Unit has used it for about 10 years. A number of other inventory organizations also have long experiences with double sampling for stratification. All adopted the design with the expectation that it was more efficient: i.e., that either sampling errors could be reduced at no extra cost or costs could be reduced without an increase in sampling error.

[1/] *In optimum allocation, field plots are distributed in proportion to stratum area times the estimated standard deviation divided by the square root of estimated cost. In proportional allocation, they are distributed in proportion to stratum area.*

Have the results justified this hope? Bickford (*3*, *4*) concluded that they did after studying the results of an inventory of eastern Maryland. In this study, double sampling for stratification proved considerably more efficient than a simple field plot survey. Nyyssönen et al. (*7*), on the other hand, found little to be gained by stratifying commercial forest field plots in volume classes. The simple field plot survey appeared almost as efficient a means of estimating total volume in the homogeneous Finnish forests tested. Aldrich and Norick (*1*), reporting on a test of poststratification in the southeastern United States, concluded that separation of forest from nonforest land was worthwhile but that further poststratification produced only marginal gains in efficiency.

THE SURVEY DESIGNS TESTED

For this report, I tested four different sampling designs to see which was most efficient in providing estimates of total volume on a typical Pacific Northwest Forest Survey Inventory Unit. In other words, I sought to determine which design would provide the most precise answer if cost were held constant. Specifically, three types of double sampling designs were compared with simple field plot surveys of equal cost.[2/] The designs tested were (1) two photo strata (commercial forest land and other) with field plots distributed in proportion to stratum area--a simple, inexpensive type of photo interpretation that has proven successful in the southeast; (2) nine photo strata (three land use classes with commercial forest land divided into seven photo volume classes (defined later) with field plots proportionally distributed; and (3) nine photo strata as above but with optimum allocation of field plots.

THE BASIC DATA

The most recent inventory data available were for all lands outside the National Forests in seven counties in northwestern Washington and five counties in central Washington. The 12 counties were inventoried in 1966 and 1967 with the standard Forest Survey double sampling design in use in the Pacific Northwest. As these were production surveys and not special studies, the quality of photo interpretation was representative of a production situation. Conditions varied from young-growth red alder and Douglas-fir to high elevation old growth to east-side pine and mixed conifer--a good cross section of the forest conditions found in the region.

Aerial photo coverage for the area was a patchwork of numerous photo projects. Photo scale varied from 1:12,000 to 1:20,000. Most photography was fairly recent--within the last 3 or 4 years--but at least one project was about 15 years old. Although part of one county was interpreted by an experienced

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[2/] *In all four designs, both photo and field plots were distributed on a systematic grid but treated as random samples.*

supervisor, most of northwestern Washington was interpreted by two graduate foresters without prior practical photo interpretation experience but with substantial inventory field experience including much practical experience in the field use of aerial photos. Both men attended an initial training session and subsequently received on-the-job training and supervision from time to time. One of the men went on to do all of the interpretation in central Washington, using the experience gained earlier.

A total of 18,548 1-acre photo plots were examined in the entire area; 350 in the smallest county and 4,114 in the largest. A member of the photo interpreter team located each photo plot by means of a transparent plot grid overlay oriented on the fiducial marks of the aerial photograph, then ascertained its land use class. If the plot was commercial forest, he estimated volume per acre, usually by predicting the stand height and crown closure, then looking up the volume in an aerial photo volume table. The interpreters were encouraged to check their height estimates periodically by means of parallax measurements.

These land use class and volume estimates enabled the interpreter to place the plot in a photo volume class. Those identified were as follows:

1. nonforest
2. noncommercial forest
3. commercial forest (in cubic-foot-per-acre classes)
   (a) 0 - 1,000
   (b) 1,001 - 2,000
   (c) 2,001 - 4,000
   (d) 4,001 - 7,000
   (e) 7,001 - 10,000
   (f) 10,001 - 15,000
   (g) 15,001+

This is the standard photo stratification scheme used by Forest Survey on the Pacific coast. It was adopted several years ago after a trial and error comparison of several combinations of strata and was in use at the time of the inventories analyzed below. Photo interpretation data for stratification schemes other than the one shown above were not available for this test, but this lack appeared to be not serious. Our earlier trial and error comparisons, as well as a recent informal test, indicated that, within reasonable limits, changes in the stratum boundaries had only minor effect on the precision of total volume estimates.

In most counties, about one-sixteenth of the photo plots were visited in the field, and an estimate of total volume per acre was obtained from plots of standard Forest Survey design (a cluster of 10 variable-radius points sampling approximately an acre). A few counties were sampled at a double intensity of about 1 in 8.

Each field plot which proved on field examination to be commercial forest cost an average of $114 in northwest Washington and $90 in central Washington.

The cost of noncommercial and nonforest field plots was assumed to be zero, since these were mostly visited enroute to or from commercial forest plots. Each photo plot cost an average of \$0.45 in northwest Washington and \$0.25 in central Washington. If photo interpretation had been limited to identification of land use class (commercial forest land, noncommercial forest land, and nonforest land), I estimated that the cost per photo plot would have been \$0.30 in the former area and \$0.15 in the latter. Aerial photos used for interpretation were all borrowed without cost, but considerable travel cost was incurred by the photo interpreters both in connection with area familiarization trips and in visiting various offices where the borrowed photos were stored. The above photo interpretation costs reflect these travel costs as well as the costs of interpreters' salaries and supervision.

THE METHOD

Using the basic data from the actual inventories, I constructed a family of inventories for each of the 12 test counties. Each of the three double sampling schemes--the two-stratum design with proportional allocation of field plots, and the nine-stratum design with proportional and with optimum allocation--was paired with a simple field plot sample of equal cost. The sampling error for each was calculated, using formula 12.12 from Cochran (*5*) for the estimated variance of the stratified sample, with the terms $\frac{n'}{n'-1}$ and g' assumed to be 1.

The inventories were realistic in that the estimates of stratum size and variance and the plot cost data came from the actual surveys. They were hypothetical in that the total number of field plots and their allocation among strata were manipulated to achieve the desired allocation and to equalize cost between paired double sampling and simple field plot designs.

The total number of photo plots used for each of the double sampling surveys was the number actually taken in the original inventory. The number of plots assumed to have been field checked depended upon the method used to allocate these plots among strata. Where field checked plots were chosen in proportion to stratum area, they were assumed to equal one-sixteenth the number of photo plots; where they were allocated optimally, they were assumed to equal one-twenty-fourth that number.

Forest Survey experience has shown this to be a reasonably efficient division of effort between photo interpretation and fieldwork. Although I was aware that the most efficient ratio of photo plots to field plots could be calculated more precisely by substituting the actual plot costs and field variances in Cochran's formula 12.9 (*5*), I chose not to, even at the risk of some slight loss in efficiency. Rather, I relied on experience gained in previous inventories--the only practical source of cost and variance data.

Proportional allocation of the field plots among the volume strata was achieved by assuming that every sixteenth photo plot would be also a field plot. Since the photo plots were distributed systematically, this insured that the field plots would be distributed proportionally.

For optimum allocation, estimates of stratum variances and photo and field plot costs were needed. Since they were already available, I used the actual costs and stratum variances calculated from our inventory data.[3/] In actual practice, these data would not be known; they would have to be estimated from experience gained on previous inventories.

RESULTS

The results of our comparison of the four designs can be seen in table 1. The yardstick used to judge each stratification scheme was the relative efficiency with which it provided estimates of total volume. The relative efficiency of any two designs of equal cost can be obtained from the ratio of the squared standard errors of the estimates they provide. I chose the simple field plot design as a base for the efficiency ratio; therefore, in my analysis it always has a value of 1.00. Under this rating system, a double sampling design with a

Table 1.--*The relative efficiency of four inventory designs in providing estimates of total timber volume*

Geographic unit	Inventory design			
	Field plot only	Two-strata	Nine-strata	
			Proportional allocation	Optimum allocation
Island County	1.00	1.58	1.68	1.68
King County	1.00	1.06	1.86	2.00
Kitsap County	1.00	1.11	1.45	1.46
Pierce County	1.00	1.07	2.96	3.52
Skagit County	1.00	1.16	1.62	1.91
Snohomish County	1.00	1.39	2.99	3.26
Whatcom County	1.00	1.25	2.70	3.26
Northwest Washington combined[1/]	1.00	1.24	1.92	2.06
Chelan County	1.00	1.16	2.11	2.44
Kittitas County	1.00	1.36	2.75	2.96
Klickitat County	1.00	1.39	2.03	2.58
Okanogan County	1.00	1.41	2.95	4.06
Yakima County	1.00	1.57	2.40	2.71
Central Washington combined[1/]	1.00	1.36	2.38	2.73
Entire test area[1/]	1.00	1.26	1.96	2.11

[1/] Combined relative efficiencies were obtained by summing the squared standard errors calculated for the individual counties.

[3/] *An exception was made for counties where variance was zero for the nonforest stratum. In order to avoid a stratum with no field sample, I allocated plots to the nonforest stratum by means of an average variance estimate borrowed from adjacent counties.*

relative efficiency of 2.00, for example, could be expected to be twice as precise (i.e., one-half the squared sampling error) as a simple field plot survey of equal cost. To put it another way, a rating of 2.00 means that it would cost twice as much to obtain an estimate of equal precision from field plots alone.

In this analysis, the nine-stratum double sample design was about twice as efficient as the simple field plot survey in providing estimates of total volume for the test area. County by county, relative efficiency ranged from 1.45 to 2.99 when field plots were proportionally allocated. When plots were optimally allocated, relative efficiency ranged from 1.46 to 4.06; but for most counties, the gain over proportional allocation was modest. For the test area as a whole, the proportionally allocated design was 1.96 times as efficient as the simple field plot survey. When optimum allocation of field plots was substituted for proportional allocation, the relative efficiency increased to 2.11, a gain of less than 8 percent.

As noted earlier, Aldrich and Norick (*1*) found in the North Carolina Piedmont that substantial gains in efficiency resulted from separating forest from nonforest land, but that poststratification of forest land into several volume classes produced only small gains in relative efficiency. These conclusions apparently do not hold true for prestratified double sampling in the Pacific Northwest. On the average, only about 25 percent of the gain realized from double sampling could be attributed to the separation of commercial forest land from other land use classes. In only one county--Island--were results similar to those reported for North Carolina and probably for the same reasons: very little zero volume forest land and not much range in volume per acre.

In my analysis, I assumed photo-to-field plot ratios of 16 to 1 for the proportionally allocated designs and 24 to 1 for the design with optimum allocation. In order to learn whether further gains in efficiency could be made by a better choice of plot ratio, I calculated the most efficient ratio for each county and for each design tested.[4/] Then I calculated the relative efficiency with which double sample surveys of the test counties would have provided volume estimates if these most efficient photo-to-field plot ratios had been used.

Although these ratios varied greatly between counties (from 12 to 1 to 24 to 1 for proportional allocation and from 14 to 1 to 32 to 1 for optimum allocation), relative sampling efficiency remained virtually unchanged from that based on arbitrary ratios of 16 to 1 and 24 to 1. The Kittitas County inventory benefited most from optimizing the photo-to-field plot ratios, but even here relative efficiency increased only by negligible amounts--from 2.75 to 2.79 for proportional allocation and from 2.96 to 3.04 for optimum allocation. As a result of further testing, I concluded that any ratio between 10 to 1 and 30 to 1 would have produced estimates of total volume almost as efficiently as the theoretically most efficient ratio.

[4/] *The most efficient ratio was calculated from Cochran* (5), *formula 12.9, rearranged as follows:* $\frac{n'}{n} = \frac{\sqrt{V_{n'} c_n}}{\sqrt{V_n c_{n'}}}$.

DISCUSSION

Double sampling for stratification has proved to be a design well suited to estimating total volume in the Pacific Northwest. As might be expected, the design showed the greatest advantage over simple field plot sampling in counties where residual patches of high volume old-growth timber are intermingled with low volume young growth and cutover stands. Stratification was least effective in counties such as Island and Kitsap where the almost total absence of high volume stands results in generally low variance and limited opportunities for stratification. Nevertheless, even here the double sample provided estimates of total volume one and a half times as efficiently as the simple field inventory.

Of course, Forest Survey samples all land, forest and nonforest alike, over a variety of ownerships and conditions. This diverse sample with its wide range of volumes is well suited to stratification. Foresters whose inventory areas are more homogeneous should expect less gain from stratification. For example, if I had restricted my sample to commercial forest land, the analysis indicates that the relative efficiency of the double sample with proportional allocation would have been about 1.60 instead of 2.00. In an inventory consisting of uniform stands with a narrow range of volumes, there might be little or no advantage to photo stratification.

Although the design utilizing optimally allocated field plots was more efficient for total volume estimation than was the design with proportional allocation, the advantage was, for the most part, quite small. Since the gain from optimum allocation comes from concentrating the field effort in those strata where within-stratum variance is high, the gain is greatest when within-stratum variances differ greatly from one stratum to the next. In this analysis, the differences were not large enough to permit large gains from optimum allocation. One might suspect that more efficiently designed stratum boundaries could increase the advantage of optimum over proportional allocation. As previously pointed out, the northern Washington data were not in a form that would permit such an analysis. However, I did use other data to compare the Forest Survey design with another more efficient scheme devised by the Dalenius method described in Cochran (5, p. 130). A comparison of the two stratification schemes in three counties in western Oregon showed only nominal differences in relative efficiency.

As pointed out earlier, optimum allocation for this analysis was based on the same cost and variance estimates that were used to calculate sampling efficiency. In normal production situations, cost and variance estimates are made in advance of sampling and may be substantially in error. If they are, a lower sampling efficiency can be anticipated.

OTHER DESIGN CONSIDERATIONS

I have limited this analysis to the consideration of the relative efficiency with which double sampling for stratification furnishes estimates of total volume. The inventory forester who must select an inventory design suited to his needs cannot limit himself to any such single objective; he must consider how well the design fits all of his varied inventory needs. Many of the volume subclasses will, of course, benefit from an improved estimate of total volume. In addition, commercial forest land estimates may be greatly improved by simultaneously double sampling for this statistic (*6*).

However, common sense suggests that some statistics are probably unrelated to photo volume classes and that these items will be estimated less efficiently by a volume class stratified double sampling design than by a simple field plot survey. An informal test of Forest Survey data indicated that volume stratification did not reduce the variance of growth estimates. These estimates, therefore, were not improved by volume stratification; their precision depended almost entirely on the number of field plots taken. Since there are fewer field plots in a double sampling survey than in a simple field plot sample of equal cost, our growth estimates were less precise.

Forest Survey experience indicates that this reduction in field plots is only about 5 percent, since photo plots are so much cheaper than field plots. Therefore, as long as field plots are distributed in proportion to stratum area, statistics unrelated to volume should not suffer much loss in precision.

Such is not necessarily the case, however, when optimum allocation is adopted. Because the design calls for a concentration of field plots in high variance strata at the expense of low variance strata, low-volume stands tend to be lightly sampled. Thus, statistics that are largely associated with such low-volume stands will probably be weak, a distinct disadvantage to the manager who is interested in treating young and understocked stands, but of no concern to the forester who is interested only in a good estimate of current volume.

SUMMARY AND CONCLUSIONS

The foregoing analysis is based on data collected in extensive timber volume inventories of areas covering much of the range of forest conditions in the Pacific Northwest. Under these conditions, double sampling for stratification provides estimates of total volume about twice as efficiently as does simple field plot sampling. Some of this gain comes from separating forest from non-forest land, but a substantial part of it is realized only when the forest plots are further stratified into timber volume classes. Although optimum allocation of field plots is more efficient than proportional allocation, the advantage is apparently slight.

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